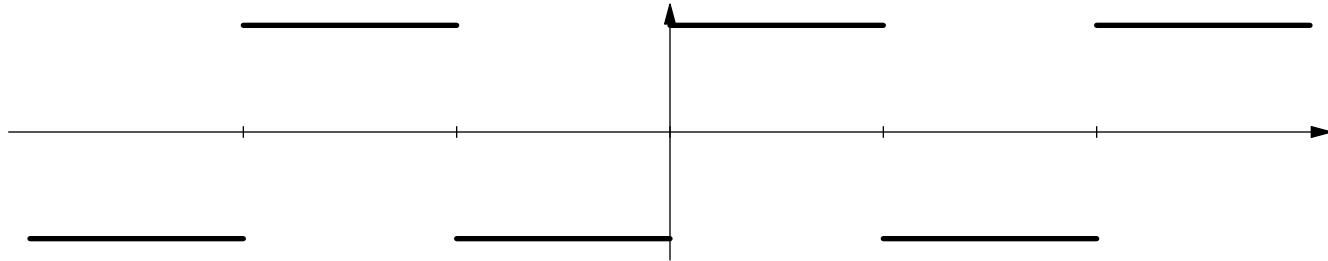


INDEX

---



INDEX

- #, 2
- ∩, 5
- , 14
- ∪, 4
- δ-ε definition, 38
- ∅, 2
- $\frac{0}{0}$  indeterminate form, 200–202, 204
- $\frac{\infty}{\infty}$  indeterminate form, 202–203
- γ, *see* Euler’s Constant
- ε, 2
- ∞, *see* infinity
- Θ, 33
- \, 6
- ₵, 3
- ⊆, 2
- 30-60-90 triangle, 21
- 4-dimensional sphere, 185
- 45-45-90 triangle, 21
- acceleration, 106
  - due to gravity, 107–108, 123
- algebraic numbers, 9
- alternating harmonic series, 239
- alternating series, 238–241
- Alternating Series Test, 239–240
- angle-addition formulas, 26, 29
- angle-subtraction formulas, 26
- annulus, 173
- antiderivative, 135, 141
  - linearity, 142
    - of a continuous function, 139
- antidifferentiation, 140, *see also* integral
- AoPS, *see* Art of Problem Solving
- arccos, *see* inverse cosine
- Archimedes spiral, 277
- arcsin, *see* inverse sine
- arctan, *see* inverse tangent
- area, 166–169
  - between curves, 166
  - ellipse, 167–169
  - in polar coordinates, 274–276
- area under a curve, 126–135
  - as sum of rectangles, 130–131
  - Darboux sum, 131
  - definite integral, 131
  - lower area, 131
  - parabola, 128–130
  - upper area, 131
- argument, 268
- Art of Problem Solving, vi, 324
- associativity, 8
- astroid, 265–267
- average value, 176–178
- Binomial Theorem, 257
- boundary point, 99
- bounded, 9
- Boundedness Theorem, 51, 55
  - proof of, 55
- Boyle’s Law, 122
- ₵, 35
- calculator, vii, 165
- cardinality, 2
- cardioid, 275–277
- Cartesian plane, 16
- Chain Rule, 73, 157
  - differentiation, 72–74
  - integration, 147–153
  - notation, 74

- proof, 84–86  
characteristic polynomial, 292  
circle  
    as parametric curve, 259–260  
    in polar coordinates, 269  
closed interval, 11  
codomain, 13  
commutativity, 8  
completeness, 9–10  
complex numbers, 35  
composition (of functions), 14  
concave down, 92, 93  
concave up, 93  
concavity, 91–95  
conditionally converge, 240–241  
continuity, 48–52  
    algebraic properties, 49  
    antiderivative, 139  
    Boundedness Theorem, 51, 55  
    definite integral, 134  
    Extreme Value Theorem, 51  
    Intermediate Value Theorem, 50, 54–55  
    localness of, 49  
continuous, 48  
converge  
    absolute, 238–241  
    conditionally, 240–241  
    improper integral, 207, 210  
    power series, 249–251  
    sequence, 221–225  
        geometric, 222  
    series, 227, 229–241  
convex, 94  
coordinates  
    polar, *see* polar coordinates  
 $\cos^{-1}$ , *see* inverse cosine  
cosecant, 24  
 $\cosh$ , 34, 185  
cosine, 20–24  
    angle-addition formula, 26  
    angle-subtraction formula, 26  
    derivative of, 70  
    domain and range of, 23  
    double-angle formula, 27  
    half-angle formula, 29  
    hyperbolic, 34  
    integral, 146–147  
    inverse, *see* inverse cosine  
    period of, 24, 26  
    Taylor series, 251–252  
cotangent, 24  
counting numbers, 8  
critical point, 96–99  
cuboids, 169  
curve  
    in polar coordinates, 269–271  
    parametric, *see* parametric curve  
curve length, *see* length  
curve sketching, 90–95  
cycloid, 261–265, 267  
cylindrical shell, 172  
damped oscillation, 104  
Darboux sum, 131  
    properties, 132  
decreasing, 88, 90, 223  
definite integral, 126, 131, *see also* integral  
    approximation techniques, 179–183  
        Simpson's Rule, 181–182, 188–190  
        Trapezoid Rule, 180–181  
    as continuous sum, 176  
    average value, 176–178  
    Chain Rule, 151–152  
    continuous function, 134  
    Fundamental Theorem of Calculus, 135–140  
    integrand, 132  
    limits of integration, 132  
    linearity, 142  
    Mean Value Theorem, 179  
    properties, 132  
    Simpson's Rule, 181–182, 188–190  
    Trapezoid Rule, 180–181  
derivative, 57, 60, 61  
    as rate of change, 90, 110  
    Chain Rule, 72–74  
        notation, 74  
        proof, 84–86  
    construction of, 59–60  
    definition, 60  
    exponential, 70–71  
    first derivative, 91  
    First Derivative Test, 101  
    implicit, 80–82  
    inverse function, 75–76  
    inverse trig functions, 76  
    Leibniz Rule, 84  
    linearity, 65  
    logarithm, 70–71  
    Mean Value Theorem, 79–80  
        proof, 86–87  
    monomial, 65–67, 77  
    Newton's Method, 113–117  
    notation, 61  
    of a constant, 90

## INDEX

---

- polynomial, 67–68
- Product Rule, 68–69
- Quotient Rule, 69, 71
- related rates, 117–122
- relationship to continuity, 62
- Rolle's Theorem, 77–79
- second derivative, 77
- Second Derivative Test, 101
- tangent line approximation, 108–113
- trig functions, 69–70
- use in curve sketching, 90–95
- where undefined, 64
  - zero, 90
- differentiable, 60
- differential equation, 279–295
  - characteristic polynomial, 292
  - Euler's Method, 297–299
  - exponential decay, 286
  - exponential growth, 285–286
  - first-order, 280
  - heating, 287
  - homogeneous, 290
  - initial condition, 279
  - integrating factor, 296
  - linear, 290–295
  - logistic, 287–289
  - radioactive decay, 286
  - relative rate (of growth), 285
  - second-order, 290–294
  - separable, 283
  - separation of variables, 282–285
  - slope field, 280–282
    - uniqueness of solution, 282
- differential notation, 61
- discrete function, 221
- disjoint (sets), 6
- distributive, 8
- diverge
  - improper integral, 207, 210
  - sequence, 221–225
  - series, 227
- Divergence Test, 230
- domain, 13
- dominate, 203–204
  - little-o notation, 214
- double-angle formula, 27, 29
- dummy variable, 13, 132
  
- e*, 31, 32
  - as a limit, 204–205
  - formula for, 249
- element (of a set), 1
  
- ellipse, 167–169
- empty set, 2, 4
- endpoints, 259
- epicycloid, 277
- equilibrium, 287
- errata, vii
- error function, 140, 185, 214
- Euler's Constant, 257
- Euler's Formula, 35, 252
- Euler's Method, 282, 297–299
- exp*, *see* exponential
- exponential, 30, 185–188
  - derivative of, 70–71
  - integral, 146–147
  - Taylor series, 248–249
- exponential function, 31, 32
- exponential growth, 285–286
- exponential indeterminate form, 204–206
- Extended Mean Value Theorem, 215
- extrema, 96
- Extreme Value Theorem, 51
- extreme values, 96
  
- Fibonacci numbers
  - Taylor series, 257
- Fibonacci sequence, 221
- field, 8
- finite set, 1
- first derivative, 91
- First Derivative Test, 101
- fixed point, 53
- Fourier series, 302
- frustum, 121
- function, 13–16
  - antiderivative, 135
  - area under graph, *see* area under a curve
  - asymptote
    - horizontal, 192
    - vertical, 198–199
  - average value, 176–178
  - codomain, 13
  - composition, 14
  - concave down, 92, 93
  - concave up, 93
  - concavity, 91–95
  - continuous, 48–52
  - convex, 94
  - critical points, 96–98
  - decreasing, 88, 90
    - strictly, 89, 90
  - derivative of, 61, *see also* derivative
  - differentiable, 60

- discrete, 221  
domain, 13  
dominate, 199, 203–204, 214  
exponential, 29–32, 185–188  
    derivative of, 70–71  
extrema, 96  
extreme values, 96  
First Derivative Test, 101  
global maximum, 99  
global minimum, 99  
graph, 16–19  
image, 15  
increasing, 88, 90  
    strictly, 89, 90  
inflection point, 93  
inverse, 14  
length, 175  
local maximum, 100  
local minimum, 100  
logarithm, 32–33, 185–188  
    derivative of, 70–71  
maximum, 99  
    global, 99  
    local, 100  
    relative, 100  
minimum, 99  
    global, 99  
    local, 100  
    relative, 100  
monotonic, 88  
    strictly, 89  
nondifferentiable, 64  
odd, 140  
optimization, 96–105  
parametric, 259  
periodic, 24  
preimage, 15  
range, 13  
rational, 193–195, 236  
real-valued, 13  
relative maximum, 100  
relative minimum, 100  
Riemann zeta function, 235  
scaling, 18–19  
strictly decreasing, 89, 90  
strictly increasing, 89, 90  
strictly monotonic, 89  
translation, 18–19  
trigonometric, 19–29  
    derivative of, 69–70  
Fundamental Theorem of Algebra, 52  
Fundamental Theorem of Calculus, 126, 135–140, 178  
gamma function, 214  
geometric sequence, 220–221, 225  
    common ratio, 221  
    convergence, 222  
geometric series, 226–229  
global maximum, 99  
global minimum, 99  
Grand Integrator, 147  
graph, 16–19  
    length, 175  
gravity, 107–108, 123  
greatest integer function, 48–49  
greatest lower bound, 10  
Green's Theorem, 267  
  
Hôpital, *see* l'Hôpital's Rule  
half-angle formula, 27, 29  
harmonic series, 230–231  
    alternating, 239  
Harvard-MIT Mathematics Tournament, iv  
HMMT, *see* Harvard-MIT Mathematics Tournament  
homogeneous, 290  
Hooke's Law, 294  
horizontal asymptote, 192  
Horizontal Line Test, 18, 19  
hyperbolic cosine, 185  
hyperbolic trig functions, 34  
hypocycloid, 266, 267  
  
identity element, 8  
image, 15  
imaginary number, 35  
imaginary part, 35  
implicit differentiation, 80–82  
    related rates, 117–122  
improper integral, 207–213  
    comparison test, 209–210  
    converge, 207, 210  
    diverge, 207, 210  
    improper at both ends, 211–213  
increasing, 88, 90, 223  
indefinite integral, 141–142, *see also* integral  
    linearity, 142  
indeterminate form  
     $\frac{0}{0}$ , 200–202, 204  
     $\frac{\infty}{\infty}$ , 202–203  
     $\infty - \infty$ , 206  
    exponential, 204–206  
index, 220  
infimum, 10  
infinite set, 1  
infinity, 191–199

## INDEX

---

- as a limit, 196–199
- not a number, 197
- inflection point, 93
- initial condition, 279
- integers, 7, 8
- integral
  - Chain Rule, 153
  - definite, *see* definite integral
  - exponential, 146–147
  - improper, *see* improper integral
  - indefinite, 141–142
  - integrand, 132
  - integration by parts, 153–157
  - limits of integration, 132
  - linearity, 142
  - partial fractions, 161–162
  - polynomials, 142–146
  - substitution, 157–161
  - trig substitution, 157–160
  - trigonometric, 146–147, 152–153, 165
- integral sign, 132
- Integral Test, 233–234, 237
- integrand, 132
- integrating factor, 296
- integration, *see* integral
  - Product Rule, 153
- integration bee, *see* MIT Integration Bee
- integration by parts, 153–157
- Intermediate Value Theorem, 50, 54
  - proof of, 54–55
- intersection, 5
- interval, 10–12
  - closed, 11
  - half-open, 11
  - open, 11
  - partition of, 130
- inverse, 8, 14
- inverse cosine, 25
- inverse function
  - derivative of, 75–76
- Inverse Function Rule, 75–76
- inverse sine, 25
  - derivative of, 76
  - integral, 159, 166
- inverse tangent, 25
  - derivative of, 76
  - integral, 159
- Taylor series, 255
- l'Hôpital's Rule, 200–206
  - $\frac{0}{0}$  indeterminate forms, 200–202, 204
  - $\frac{\infty}{\infty}$  indeterminate forms, 202–203
- exponential indeterminate forms, 204–206
  - proof, 215–219
- least upper bound, 10
- left Riemann sum, 135
- Leibniz Rule, 84
- Leibniz, Gottfried, iii
- length, 173–176, 265
  - of parametric curve, 265, 278
- limaçon, 273, 276
- limit, 37–48
  - $\delta$ - $\epsilon$  definition of, 38
  - at infinity, 191–196
    - as finite limit, 195–196
  - comparison of, 43
  - infinite, 196–199
  - one-sided, 45–47
  - properties, 42–43
  - rational function, 193–195
  - sequence, 222
  - Squeeze Theorem, 44, 48
  - uniqueness of, 41–42
- Limit Comparison Test, 235–237
- limits of integration, 132
- line
  - as parametric curve, 260–261
  - in polar coordinates, 273, 277
- linear, 65, 142
- linear approximation, 111
- links, vii, 303
- Lissajous curve, 267
- little-o notation, 214
- ln, 32, *see also* logarithm
- local, 49
  - local linearization, 110
  - local maximum, 100, 101
  - local minimum, 100, 101
- log, 32, *see also* logarithm
- logarithm, 32, 185–188
  - derivative of, 70–71
  - integral, 156
  - Taylor series, 252–254
- logistic equation, 287–289
- lower area, 131
- lower bound, 9
- lower Darboux integral, 131
- lower Darboux sum, 131
- Maclaurin polynomial, 245
- Maclaurin series, 247
- magnitude, 268
- maximal element, 11
- maximum, 11, 99

- Mean Value Theorem, 79–80, 86, 179  
extended, 215  
proof, 86–87  
member (of a set), 1  
midpoint Riemann sum, 135  
minimal element, 11  
minimum, 11, 99  
MIT Integration Bee, 147, 184  
monotonic, 88, 223
- $\mathbb{N}$ , 8  
natural logarithm, 32, 185  
natural numbers, 8  
Newton's Law of Heating, 287  
Newton's Method, 113–117  
Newton, Isaac, iii  
normal distribution, 301  
numbers  
algebraic, 9  
integers, 8  
positive, 7  
natural, 8  
rational, 8  
real, 9  
completeness of, 9–10  
construction of, 9–10  
transcendental, 9
- one-sided limits, 45–47  
open interval, 11  
operator notation, 61  
optimization, 96–105
- $p$ -series, 230, 232–235  
parameterization, 259  
parametric curve, 259–266  
astroid, 265–267  
circle, 259–260  
cycloid, 261–265, 267  
hypocycloid, 267  
length, 265, 278  
line, 260–261  
polar curve, 271  
speed, 264–265  
tangent line, 262–264
- parametric function, 259  
partial fractions, 161–162  
partial sum, 226, 227  
partition, 130  
period, 24  
periodic, 24  
polar coordinates, 267–276
- Archimedes spiral, 277  
area, 274–276  
argument, 268  
cardioid, 275–277  
circle, 269  
conversion to/from rectangular, 268  
curves, 269–271  
epicycloid, 277  
limaçon, 273, 276  
line, 273, 277  
magnitude, 268  
rose, 269–270, 278  
area, 275  
tangent line, 271–273
- positive integers, 7  
power series, 247–255  
convergence, 249–251  
radius of convergence, 249–251
- preimage, 15  
probability density function, 301  
Product Rule, 69  
differentiation, 68–69  
integration, 153
- proof by contradiction, 9  
proper subset, 3  
Putnam, *see* William Lowell Putnam Mathematical Competition  
pyramid, 169–170
- $\mathbb{Q}$ , 8  
 $\mathbb{Q}$ , 9  
quadratic approximation, 241–243  
Quotient Rule, 69, 71
- $\mathbb{R}$ , 9  
Racetrack Theorem, 123  
radians, 20  
radius of convergence, 249–251  
range, 13  
rate of change, 90, 110  
Ratio Test, 236–237  
Taylor series, 250–251  
rational function, 193–195, 198–199  
series, 236
- rational numbers, 8  
real numbers, 9  
construction of, 9–10  
real part, 35  
real-valued, 13  
rectangular coordinates, 268  
recursive, 221  
recursive formula, 221

## INDEX

---

- related rates, 117–122  
relative maximum, 100  
relative minimum, 100  
resources, vi  
Riemann Hypothesis, 235  
Riemann sum, 134–135  
Riemann zeta function, 235  
right Riemann sum, 135  
Rolle's Theorem, 77–79  
Root Test, 238  
rose, 269–270, 278  
    area, 275  
Rule of Seventy-two, 124  
Russell's paradox, 34
- secant, 24  
secant line, 57, 58  
second derivative, 77, 91  
Second Derivative Test, 101  
second-order, 243  
separable, 283  
separation of variables, 282–285  
sequence, 220–225  
    bounded, 222–225  
    converge, 221–225  
    decreasing, 222–224  
    diverge, 221–225  
    Fibonacci, 221  
    geometric, *see* geometric sequence  
    increasing, 222–224  
    index, 220  
    limit, 222  
    monotonic, 222–224  
    recursive definition, 221  
series, 226–255  
    absolute convergence, 238–241  
    alternating, 238–241  
    alternating harmonic, 239  
    Alternating Series Test, 239–240  
    conditionally converge, 240–241  
    converge, 227, 229–241  
    diverge, 227  
    Divergence Test, 230  
    geometric, 226–229  
    harmonic, 230–231  
    Integral Test, 233–234, 237  
    Limit Comparison Test, 235–237  
    Maclaurin, 247, *see also* Taylor series  
        partial sum, 226, 227  
    power, *see* power series  
    Ratio Test, 236–237
- rational functions, 236  
Root Test, 238  
Series Comparison Test, 231–232  
sum, 226  
Taylor, *see* Taylor series  
telescoping, 229  
Series Comparison Test, 231–232  
set, 1–7  
    cardinality, 2  
    difference, 6, 7  
    disjoint, 6  
    distributive law, 6  
    element, 1  
    empty, 2, 4  
    finite, 1  
    infinite, 1  
    intersection, 5  
    member, 1  
    Russell's paradox, 34  
    subset, 2  
        proper, 3  
    superset, 3  
    symmetric difference, 33  
    union, 4  
set difference, 6, 7  
sign graph, 90  
Simpson's Rule, 181–182, 188–190  
 $\sin^{-1}$ , *see* inverse sine  
sine, 20–24  
    angle-addition formula, 26  
    angle-subtraction formula, 26  
    derivative of, 69–70  
    domain and range of, 23  
    double-angle formula, 27  
    half-angle formula, 29  
    hyperbolic, 34  
    integral, 146–147  
    inverse, *see* inverse sine  
    period of, 24, 26  
        Taylor series, 251–252  
sinh, 34  
slicing, 170–171  
slope field, 280–282  
Snell's Law, 124  
solid of revolution, 171–173  
sphere, 171  
    4-dimensional, 185  
square wave, 302  
Squeeze Theorem, 44, 48  
strictly decreasing, 30, 89, 90, 223  
strictly increasing, 89, 90, 223  
strictly monotonic, 89

- subset, 2
  - proper, 3
  - warning about notation, 3
- substitution method, 157–161
- sum, 226, 227
- superset, 3
- supremum, 10, 223
- symmetric difference, 33
- $\tan^{-1}$ , *see* inverse tangent
- tangent, 20
  - angle-addition formula, 29
  - derivative of, 70
  - domain and range of, 23
  - double-angle formula, 29
  - half-angle formula, 29
  - inverse, *see* inverse tangent
  - period of, 26
- tangent line, 57–60, 263
  - approximation using, 108–113
  - definition, 60
  - in polar coordinates, 271–273
  - to parabola, 57–58
  - to parametric curve, 262–264
- tangent line approximation, 108–113, 241
  - error, 110–111, 113, 124
  - Newton's Method, 113–117
- Taylor polynomial, 241–247
  - error, 245–247
- Taylor series, 247–255
  - differentiation, 254–255
  - exponential, 248–249
  - logarithm, 252–254
  - radius of convergence, 249–251
  - Ratio Test, 250–251
  - trigonometric, 251–252, 255
- telescoping, 136, 229
- torus, 178
- transcendental number, 9
- Trapezoid Rule, 180–181
- triangle
  - 30-60-90, 21
  - 45-45-90, 21
- trig substitution, 157–160
- union, 4
- unit circle, 22
- upper area, 131
- upper bound, 9
- upper Darboux integral, 131
- upper Darboux sum, 131
- velocity, 106
- along parametric curve, 264–265
- vertical asymptote, 198–199
- Vertical Line Test, 17, 19
- volume, 169–173
  - 4-dimensional sphere, 185
  - by slicing, 170–171
  - cylindrical shell method, 172
  - pyramid, 169–170
  - solid of revolution, 171–173
  - sphere, 171
  - torus, 178
- whole numbers, 8
- William Lowell Putnam Mathematical Competition, iv
- Wolfram|Alpha, vii
- $\mathbb{Z}$ , 8